Annex D
(informative)

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INTERNATIONAL STANDARD

ISO 9845-1

First edition
1992-10-15

Solar energy — Reference solar spectral irradiance at the ground at different receiving conditions —

Part 1:
Direct normal and hemispherical solar irradiance for air mass 1,5

Énergie solaire — Rayonnement solaire spectral de référence au sol sous différentes conditions de réception —

Partie 1: Rayonnement solaire direct normal et hémisphérique pour une masse d'air de 1,5

Reference number
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Contents

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 9845-1 was prepared by Technical Committee ISO/TC 180, *Solar energy*, Sub-Committee SC 1, *Climate -- Measurement and data*.

ISO 9845 consists of the following parts, under the general title *Solar energy — Reference solar spectral irradiance at the ground at different receiving conditions*:

— *Part 1: Direct normal and hemispherical solar irradiance for air mass 1,5*

Annexes A, B, C and D of this part of ISO 9845 are for information only.

Introduction

Absorbance, reflectance and transmittance of terrestrial solar energy are important factors in solar thermal system performance, photovoltaic system performance, materials studies, biomass studies and solar simulation activities. These optical properties are normally functions of wavelength, which requires that the spectral distribution of the solar flux be known before the solar weighted property can be calculated. In order to compare the performance of competitive products, a reference standard solar spectral irradiance distribution is desirable.

The tables in this part of ISO 9845 provide spectral irradiance data. These modelled data, based on conditions selected in ASTM E 891-87, *Terrestrial direct normal solar spectral irradiance for air mass 1,5*, and ASTM E 892-87, *Terrestrial direct normal solar spectral irradiance at air mass 1,5 for a 37° tilted surface*, form the subject of the first of a series of standards dealing with spectral irradiance at different receiving conditions such as different albedos, tilt angles, etc.

The tables in this part of ISO 9845 are modelled data that were generated using a zero air mass solar spectrum based on the revised extraterrestrial spectrum of Neckel and Labs[1], the BRITE [3][4] Monte Carlo radiative transfer code, and the 1962 US Standard Atmosphere[5] with a rural aerosol [6] [7][8]. Further details are presented in annex A.

The extraterrestrial spectrum that was used to generate the terrestrial spectrum was provided by Fröhlich and Wehrli[1] and is a revised and extended Neckel and Labs[2] spectrum. Neckel and Labs revised their spectrum by employing newer solar limb-darkening data to convert from radiance to irradiance, as reported by Fröhlich[9], citing the study by Hardorp[10]. Comparisons by Fröhlich with calibrated sunphotometer data from Manua Loa, Hawaii[11], indicate that this new extraterrestrial spectrum is one of the best currently available.

The development of the terrestrial solar spectrum data is based on work reported by Bird *et al.* [12][13]. In computing the terrestrial values using the BRITE Monte Carlo radiation transfer code, the authors cited took the iterations to 2,450 0 μm only. The spectrum is extended to 4, 045 0 μm using sixteen E_{λ_i} values from ASTM E 891-87 and ASTM E 892-87. Irradiance values in ASTM E 891-87 were computed from the extraterrestrial spectrum. The additional data points were added to account for the solar irradiance in this region which accounts for approximately 1,5 % of the total irradiance between 0,305 0 μm and 4,045 0 μm.

Further parts of ISO 9845 will consider recent improvements in the basic data and modelling techniques leading to better accuracy.

Solar energy — Reference solar spectral irradiance at the ground at different receiving conditions —

Part 1:
Direct normal and hemispherical solar irradiance for air mass 1,5

1 Scope

This part of ISO 9845 provides an appropriate standard spectral irradiance distribution to be used in determining relative performance of solar thermal, photovoltaic, and other systems, components and materials where the direct and hemispherical irradiance component is desired. Possible shortcomings caused by modelling of the ground component at a constant albedo of 0,2 are explicitly noted.

The tables presented in this part of ISO 9845 define an air mass 1,5 solar spectral irradiance, for use in all solar applications where a standard spectral irradiance is required, for the direct normal radiation — 5,8° field-of-view angle — and hemispherical radiation on an equator-facing, 37° tilted plane for an albedo of 0,2. These tables are intended to represent ideal clear sky conditions.

2 Definitions

For the purposes of this part of ISO 9845, the following definitions apply.

2.1 air mass zero (AM0): Solar radiation quantities outside the earth's atmosphere at the mean earth-sun distance.

2.2 air mass (AM): Ratio of the mass of atmosphere in the actual observer—sun path to the mass that would exist if the observer were at sea level, at standard barometric pressure, and the sun were directly overhead.

NOTE 1 Air mass varies with the elevation of the sun and the local barometric pressure, which changes with altitude. For a sun zenith angle, Z, of 62° or less, and local atmospheric pressure, P, where P_0 is standard atmospheric pressure, $AM = P/(P_0 \cdot \cos Z)$.

2.3 direct solar irradiance: On a given plane receiver surface, the ratio of the radiant fluxes received from a small solid angle centred on the sun's disk to the area of that surface (unit: watts per square metre, $W \cdot m^{-2}$).

NOTE 2 If the plane is perpendicular to the axis of the solid angle, the direct normal solar irradiance is received. For appropriate radiometers of modern design, the applied solid angles correspond to field-of-view angles of less than 6°.

2.4 hemispherical solar irradiance: On a given plane, the ratio of the solar radiant flux received from the sky hemisphere above — including the direct solar radiant flux — to the area of the plane (unit: watts per square metre, $W \cdot m^{-2}$).

2.5 spectral solar irradiance (E_λ): Solar irradiance E per unit wavelength interval at a given wavelength λ (unit: watts per square metre per micrometre, $W \cdot m^{-2} \cdot \mu m^{-1}$).

$$E_\lambda = dE/d\lambda$$

NOTE 3 The reference spectra are evaluated in the range of 0,305 μm to 4,045 μm. The relevant spectral range of the measurement of the solar radiation is confined to the range from 0,3 μm to 3 μm. This accounts for 98,5 % of the spectra (further details are given in ISO 9060:1990, *Solar energy — Specification and classification of instruments for measuring hemispherical solar and direct solar radiation*). However, the spectra in this part of ISO 9845 are confined to the range from 0,305 μm to 4,045 μm.

2.6 meteorological optical range: Horizontal distance V at which the contrast between a black target and the sky above the horizon is equal to the threshold contrast ε_0:

$$V = \frac{1}{\sigma} \ln \frac{1}{\varepsilon_0}$$

where σ is the atmospheric extinction coefficient in reciprocal metres, and ε_0 is a parameter equal to 0,05; thus

$$\ln \frac{1}{\varepsilon_0} \approx 3,0.$$

3 Application of the spectral data for deriving effective solar irradiances and solar spectrum weighted quantities

3.1 Spectrally modified total solar irradiance

If $R(\lambda)$ is the wavelength-dependent property of a device (such as responsivity, transmittance, reflectance, absorptance) and $E_\lambda(\lambda)$ represents the solar spectral irradiance, then E_s, the effective total solar irradiance weighted with the spectral property of this device, can be calculated as an integral of the product of $E_\lambda(\lambda)$ and $R(\lambda)$.

$$E_s = \int_0^\infty R(\lambda) E_\lambda \, d\lambda \qquad \ldots (1)$$

3.2 Solar spectrum weighted property

The mean value R_s of the property $R(\lambda)$, which is effective if the total solar spectrum is applied, can in general be calculated by the following equation.

$$R_s = \frac{\int_0^\infty R(\lambda) E_\lambda \, d\lambda}{\int_0^\infty E_\lambda \, d\lambda} \qquad \ldots (2)$$

Since the spectral property and the spectral irradiance are usually known as discrete values, the integration shall be performed as summations so that equations (1) and (2) become, respectively,

$$E_s = \sum_{i=1}^{N} R(\lambda_i) E_{\lambda_i} \Delta\lambda_i \qquad \ldots (3)$$

and

$$R_s = \frac{E_s}{\sum_{i=1}^{N} E_{\lambda_i} \Delta\lambda_i} \qquad \ldots (4)$$

where λ_i is the wavelength of the ith point out of N for which the spectral data are known. The values represent the practical limits of the summation.

3.3 Weighted ordinate method

The weighted ordinate method is described by the summations indicated in equations (3) and (4) by using the values λ_i, $\Delta\lambda_i$ and E_{λ_i} given in table 1. Interpolation between nearby values of the spectral response, $R(\lambda)$, is often required since the wavelengths of digitally recorded response curves may differ from those given in table 1.

3.4 Selected ordinate method

In the selected ordinate method the solar spectral irradiance is divided into m wavelength intervals, each containing $1/m$ of the total solar irradiance, $E_{0 \to \infty}$ and having a centroid wavelength λ_i. This results in all the products $E_{\lambda_i} \Delta\lambda_i$ being equal to $E_{0 \to \infty}/m$, allowing them to be factored from the summation. Equations (3) and (4) respectively reduce to the following:

$$E_s = \frac{E_{0 \to \infty}}{m} \sum_{i=1}^{m} R(\lambda_i) \qquad \ldots (5)$$

and

$$R_s = 1/m \sum_{i=1}^{m} R(\lambda_i) \qquad \ldots (6)$$

Appropriate values for the centroid wavelengths for 100 and 50 selected ordinates are provided in tables 2 and 3. For devices with relatively smooth spectral responsivity, 50-point selected ordinates are adequate. For devices with spectral responses that contain complex structures, the 100-point selected ordinate or weighted ordinate method should be used.

4 Validation of accuracy

The values of direct normal irradiance presented here are the same as those measured with a 5,8° field-of-view normal incidence pyrheliometer, which allows a small amount of circumsolar (diffuse) radiation to be detected. For the type of atmospheric conditions modelled here, this circumsolar radiation adds approximately 1 % to the measured direct irradiance.

NOTE 4 In the spectral region of interest (0,305 0 µm to 4,045 0 µm), the BRITE Monte Carlo computer code has not been adequately verified with experimental data. A comparison of the direct normal irradiance resulting from this part of ISO 9845 has been compared with other rigorous codes. The comparison indicates that the various models agree within ± 5 % in spectral regions where there is significant radiation present. Almost all of the differences in the results of these rigorous codes can be traced to differences in the molecular absorption coefficients used as input to the codes.

Single aberrant values (caused by e.g. unsuitable shading methods) shall not be considered for the tables in this part of ISO 9845.

5 Standard data of direct normal solar irradiance, hemispherical solar irradiance on an equator-facing, 37° tilted plane and normalized hemispherical solar irradiance

Table 1 presents:

- direct normal solar spectral irradiance in the wavelength range from 0.305 0 µm to 4,045 0 µm;
- hemispherical solar spectral irradiance, incident on a 37° tilted plane, equator-facing;
- normalized solar spectral irradiance (normalized to solar irradiance of 1 000 W·m^{-2}), hemispherical.

The values in table 1 relate to AM = 1,5 between surface-plane and sun, and a field-of-view angle of 5,8° (ground albedo: 0,2).

The columns in table 1 give values for the following parameters:

- column 1: wavelength λ_i in µm;
- columns 2, 5 and 8: mean value of spectral irradiance E_{λ_i} in watts per square metre per micrometre, W·m^{-2}·µm^{-1};
- columns 3, 6 and 9: integrated solar irradiance $E_{0-\lambda_i}$ in watts per square metre, W·m^{-2};
- columns 4, 7 and 10: the fraction F_{λ_i} of solar irradiance in the wavelength range 0 to λ_i.

NOTE 5 There is an insignificant amount of radiation reaching the earth's surface at wavelengths below 0,3 µm. See also the plots of solar irradiance in figures C.1 and C.2.

Table 2 presents 100 selected ordinates for:

- direct normal solar spectral irradiance in the spectral range from 0,305 0 µm to 4,045 0 µm incident on a tilted plane;
- hemispherical solar spectral irradiance incident on a 37° tilted plane, equator-facing.

The values in table 2 relate to AM = 1,5 between surface-plane and sun, and a field-of-view angle of 5,8° (ground albedo: 0.2).

The columns in table 2 give the values for the following parameters:

- column 1: the fraction F_{λ_k} of solar irradiance in the wavelength range 0 to λ_k;
- columns 2 and 4: integrated solar irradiance $E_{0-\lambda_k}$ in watts per square metre, W·m^{-2};
- columns 3 and 5: wavelength λ_k in micrometres, µm.

Table 3 presents 50 selected ordinates for the same parameters given in table 2.

Table 1 — Spectral solar irradiance

Wavelength	Direct normal solar spectral irradiance from 0,305 0 µm to 4,045 0 µm			Hemispherical solar spectral irradiance incident on a 37° tilted plane, equator-facing			Normalized solar spectral hemispherical irradiance (normalized to 1 000 W·m⁻²)		
λ_i	E_{λ_i}	$E_{0\to\lambda_i}$	F_{λ_i}	E_{λ_i}	$E_{0\to\lambda_i}$	F_{λ_i}	E_{λ_i}	$E_{0\to\lambda_i}$	F_{λ_i}
1	2	3	4	5	6	7	8	9	10
0,305 0	3,4	0,02	0,000 0	9,2	0,06	0,000 1	9,5	0,06	0,000 1
0,310 0	15,6	0,07	0,000 1	40,8	0,19	0,000 2	42,3	0,19	0,000 2
0,315 0	41,1	0,21	0,000 3	103,9	0,55	0,000 6	107,8	0,57	0,000 6
0,320 0	71,2	0,49	0,000 6	174,4	1,25	0,001 3	181,0	1,29	0,001 3
0,325 0	100,2	0,92	0,001 2	237,9	2,28	0,002 4	246,0	2,36	0,002 4
0,330 0	152,4	1,55	0,002 0	381,0	3,82	0,004 0	395,3	3,97	0,004 0
0,335 0	155,6	2,32	0,003 0	376,0	5,72	0,005 9	390,1	5,93	0,005 9
0,340 0	179,4	3,16	0,004 1	419,5	7,70	0,008 0	435,3	7,99	0,008 0
0,345 0	186,7	4,08	0,005 3	423,0	9,81	0,010 2	438,9	10,18	0,010 2
0,350 0	212,0	5,07	0,006 6	466,2	12,03	0,012 5	483,7	12,49	0,012 5
0,360 0	240,5	7,34	0,009 5	501,4	16,87	0,017 5	520,3	17,51	0,017 5
0,370 0	324,0	10,16	0,013 2	642,1	22,59	0,023 4	666,2	23,44	0,023 4
0,380 0	362,4	13,59	0,017 7	686,7	29,23	0,030 3	712,5	30,33	0,030 3
0,390 0	381,7	17,31	0,022 5	649,6	36,14	0,037 5	720,7	37,50	0,037 5
0,400 0	556,0	22,00	0,028 6	976,4	44,49	0,046 2	1 013,1	46,17	0,046 2
0,410 0	656,3	28,06	0,036 5	1 116,2	54,96	0,057 0	1 158,2	57,02	0,057 0
0,420 0	690,8	34,80	0,045 3	1 141,1	66,24	0,068 7	1 184,0	68,74	0,068 7
0,430 0	641,9	41,46	0,054 0	1 033,0	77,11	0,080 0	1 071,9	80,01	0,080 0
0,440 0	798,5	48,66	0,063 3	1 254,8	88,55	0,091 9	1 302,0	91,88	0,091 9
0,450 0	956,6	57,44	0,074 8	1 470,7	102,18	0,106 0	1 526,0	106,02	0,106 0
0,460 0	990,0	67,17	0,087 4	1 541,6	117,24	0,121 7	1 599,6	121,65	0,121 7
0,470 0	998,0	77,12	0,100 4	1 523,7	132,57	0,137 6	1 581,0	137,55	0,137 6
0,480 0	1 046,1	87,34	0,113 7	1 569,3	148,03	0,153 6	1 628,3	153,60	0,153 6
0,490 0	1 005,1	97,59	0,127 0	1 483,4	163,30	0,169 4	1 539,2	169,44	0,169,4
0,500 0	1 026,7	107,75	0,140 2	1 492,6	178,18	0,184,9	1 548,7	184,88	0,184 9
0,510 0	1 066,7	118,22	0,153 9	1 529,0	193,29	0,200 6	1 586,5	200,55	0,200 6
0,520 0	1 011,5	128,61	0,167 4	1 431,1	208,09	0,215 9	1 484,9	215,91	0,215 9
0,530 0	1 084,9	139,89	0,181 0	1 515,4	222,82	0,231 2	1 572,4	231,20	0,231 2
0,540 0	1 082,4	149,93	0,195 1	1 494,5	237,87	0,246 8	1 550,7	246,81	0,246,8
0,550 0	1 102,2	160,85	0,209 4	1 504,9	252,87	0,262 4	1 561,5	262,38	0,262 4
0,570 0	1 087,4	182,75	0,237 9	1 447,1	282,39	0,293 0	1 501,5	293,01	0,293 0
0,590 0	1 024,3	203,87	0,265 3	1 344,9	310,30	0,322 0	1 395,5	321,98	0,322 0
0,610 0	1 088,8	225,00	0,292 8	1 431,5	338,07	0,350 8	1 485,3	350,78	0,350 8
0,630 0	1 062,1	246,51	0,320 8	1 382,1	366,20	0,380 0	1 434,1	379,98	0,380 0
0,650 0	1 061,7	267,74	0,348 5	1 368,4	393,71	0,408 5	1 419,9	408,52	0,408 5
0,670 0	1 046,2	288,82	0,375 9	1 341,8	420,81	0,436 6	1 392,3	436,64	0,436 6
0,690 0	859,2	387,88	0,400 7	1 089,0	445,12	0,461 9	1 130,0	461,86	0,461 9
0,710 0	1 002,4	326,49	0,424 9	1 269,0	468,70	0,486 3	1 316,7	486,33	0,486 3
0,718 0	816,9	333,77	0,434 4	973,7	477,67	0,495 6	1 010,3	495,64	0,495 6
0,724 4	842,8	339,08	0,441 3	1 005,4	484,00	0,502 2	1 043,2	502,21	0,502 2
0,740 0	971,0	353,23	0,459 7	1 167,3	500,95	0,519 8	1 211,2	519,79	0,519 8
0,752 5	956,3	365,27	0,475 4	1 150,6	515,44	0,534 8	1 193,9	534,82	0,534 8
0,757 5	942,2	378,82	0,481 6	1 132,9	521,15	0,540 7	1 175,5	540,75	0,540 7
0,762 5	524,8	373,69	0,486 4	619,8	525,53	0,545 3	643,1	545,29	0,545 3
0,767 5	830,7	377,08	0,490 8	993,8	529,56	0,549 5	1 030,7	549,48	0,549 5

Wavelength	Direct normal solar spectral irradiance from 0,305 0 µm to 4,045 0 µm			Hemispherical solar spectral irradiance incident on a 37° tilted plane, equator-facing			Normalized solar spectral hemispherical irradiance (normalized to 1 000 W·m⁻²)		
λ_i	E_{λ_i}	$E_{0\to\lambda_i}$	F_{λ_i}	E_{λ_i}	$E_{0\to\lambda_i}$	F_{λ_i}	E_{λ_i}	$E_{0\to\lambda_i}$	F_{λ_i}
1	2	3	4	5	6	7	8	9	10
0,780 0	908,9	387,95	0,504 9	1 090,1	542,58	0,563 0	1 131,1	562,99	0,563 0
0,800 0	873,4	405,77	0,528 1	1 042,4	563,91	0,585 1	1 081,6	585,12	0,585 1
0,816 0	712,0	418,46	0,544 6	818,4	578,79	0,600 6	849,2	600,56	0,600 6
0,823 7	660,2	423,74	0,551 5	756,5	584,86	0,606 9	785,0	606,85	0,606 9
0,831 5	765,5	429,30	0,558 0	883,2	591,25	0,613 5	916,4	613,49	0,613 5
0,840 0	799,8	435,95	0,567 4	925,1	598,94	0,621 5	959,9	621,46	0,621 5
0,860 0	815,2	452,10	0,588 4	943,4	617,62	0,640 9	978,9	640,85	0,640 9
0,880 0	778,3	468,04	0,609 2	899,4	636,05	0,660 0	933,2	659,97	0,660 0
0,905 0	630,4	485,65	0,632 1	721,4	656,31	0,681 0	748,5	680,99	0,681 0
0,915 0	565,2	491,62	0,639 9	643,3	663,13	0,688 1	667,5	688,07	0,688 1
0,925 0	586,4	497,38	0,647 4	665,3	669,68	0,694 9	690,3	694,86	0,694 9
0,930 0	348,1	499,72	0,650 4	389,0	672,31	0,697 6	403,6	697,60	0,697 6
0,937 0	224,2	501,72	0,653 0	248,9	674,55	0,699 9	258,3	699,91	0,699 9
0,948 0	271,4	504,45	0,656 6	302,2	677,58	0,703 1	313,6	703,06	0,703 1
0,965 0	451,2	510,59	0,664 6	507,7	684,46	0,710 2	526,8	710,20	0,710 2
0,980 0	549,7	518,10	0,674 3	623,0	692,94	0,719 0	646,4	719,00	0,719 0
0,993 5	630,1	526,06	0,684 7	719,7	702,00	0,728 4	746,8	728,41	0,728 4
1,040 0	582,9	554,26	0,721 4	665,5	734,21	0,761 8	690,5	761,82	0,761 8
1,070 0	539,7	571,10	0,743 3	614,4	753,41	0,781 7	637,5	781,74	0,781 7
1,100 0	366,2	584,69	0,761 0	397,6	768,59	0,797 5	412,6	797,49	0,797 5
1,120 0	98,1	589,33	0,767 0	105,8	773,61	0,802 7	108,9	802,71	0,802 7
1,130 0	169,5	590,67	0,768 8	182,2	775,05	0,804 2	189,1	804,20	0,804 2
1,137 0	118,7	591,68	0,770 1	127,4	776,13	0,805 3	132,2	805,32	0,805 3
1,161 0	301,9	596,73	0,776 7	326,7	781,58	0,811 0	339,0	810,98	0,811 0
1,180 0	406,8	603,46	0,785 4	443,3	788,90	0,818 6	460,0	818,57	0,818 6
1,200 0	375,2	611,28	0,795 6	408,2	797,41	0,827 4	423,6	827,40	0,827 4
1,235 0	423,6	625 26	0,813 8	463,1	812,66	0,843 2	480,5	843,22	0,843 2
1,290 0	365,7	546,96	0,842 1	398,1	836,34	0,867 8	413,1	867,80	0,867 8
1,320 0	223,4	655,80	0,853 6	241,1	845,93	0,877 7	250,2	877,75	0,877 7
1,350 0	30,1	659,60	0.858 5	31,3	850,02	0,882 0	32,5	881,99	0,882 0
1,395 0	1,4	660,31	0.859 4	1,5	850.76	0,882 8	1,6	882,95	0,882 8
1,442 5	51,6	661.57	0,861 1	53,7	852,07	0,884 1	55,7	884,11	0,884 1
1,462 5	97,0	663,06	0,863 0	101,3	853,62	0,885 7	105,1	885,72	0,885 7
1,477 0	97,3	664,46	0,864 8	101,7	855,09	0,887 2	105,5	887,25	0,887 2
1,497 0	167,1	667,11	0.868 3	175.5	857,86	0,890 1	182.1	890,12	0,890 1
1,520 0	239,3	671,78	0,874 4	253,1	862,79	0,895 2	262.6	895,25	0,895 2
1,539 0	248,8	676,42	0,880 4	264,3	867,70	0,900 3	274.2	900,34	0,900 3
1,558 0	249,3	681,15	0,886 6	265,0	872,73	0,905 6	275.0	905,56	0,905 6
1,578 0	222,3	685,87	0.892 7	235,7	877,74	0,910 8	244.6	910,75	0,910 8
1,592 0	227,3	689,01	0,896 8	238.4	881,06	0.914 2	247.4	914,19	0,914 2
1,610 0	210,5	692.95	0,901 9	220,4	885.19	0,918 5	228.7	918,48	0,918 5
1,630 0	224,7	697,31	0,907 6	235,6	889,75	0,923 2	244,5	923,21	0,923 2
1,646 0	215,9	700,83	0.912 2	226,3	893,44	0,927 0	234.8	927,85	0,927 0
1,678 0	202,8	707,53	0,920 9	121,5	900.46	0,934 3	220.5	934,33	0,934 3
1,740 0	158,2	718,72	0,935 5	165,3	912,18	0,946 5	171.5	946,48	0,946 5
1,800 0	28,6	724,33	0,942 8	29,6	918.02	0,952 5	30,7	952,55	0,952 5
1,860 0	1,8	725,24	0,943 9	1.9	918,97	0,953 5	2,0	953,53	0,953 5
1,920 0	1,1	725,32	0,944 1	1,2	919.06	0.953 6	1,2	953,63	0,953 6
1,960 0	19,7	725,74	0,944 6	20,4	919,49	0,954 1	21.2	954,07	0,954 1
1,985 0	84,9	727,05	0,946 3	87,8	920,85	0,955 5	91,1	955,48	0,955 5

Wavelength	Direct normal solar spectral irradiance from 0,305 0 µm to 4,045 0 µm			Hemispherical solar spectral irradiance incident on a 37° tilted plane, equator-facing			Normalized solar spectral hemispherical irradiance (normalized to 1 000 W·m^{-2})		
λ_i	E_{λ_i}	$E_{0-\lambda_i}$	F_{λ_i}	E_{λ_i}	$E_{0-\lambda_i}$	F_{λ_i}	E_{λ_i}	$E_{0-\lambda_i}$	F_{λ_i}
1	2	3	4	5	6	7	8	9	10
2,005 0	25,0	728,15	0,947 7	25,8	921,98	0,956 7	26,8	956,66	0,956 7
2,035 0	92,5	729,91	0,950 0	95,9	923,81	0,958 6	99,5	958,55	0,958 6
2,065 0	56,3	732,14	0,952 9	58,2	926,12	0,960 9	60,4	960,95	0,960 9
2,100 0	82,7	734,57	0,956 1	85,9	928,64	0,963 6	89,1	963,57	0,963,6
2,148 0	76,2	738,39	0,961 1	79,2	932,60	0,967 7	82,2	967,68	0,967 7
2,198 0	66,4	741,95	0,965 7	68,9	936,30	0,971 5	71.5	971,52	0,971 5
2,270 0	65,0	746,68	0,971 9	67,7	941,22	0,976 6	70.2	976,62	0,976,6
2,360 0	57,6	752,20	0,979 0	59,8	946,96	0,982 6	62,0	982,57	0,982 6
2,450 0	19.8	755,68	0,983 6	20,4	950,52	0,986 3	21.2	986,32	0,986 3
2,494 0	17,0	756,49	0,984 6	17,8	951,41	0,987 2	18,5	987,19	0,987 2
2,537 0	3,0	756,92	0,985 2	3,1	951,86	0,987 7	3,2	987,66	0,987 7
2,941 0	4,0	758,34	0,987 0	4,2	953,33	0,989 2	4.4	989,19	0,989 2
2,973 0	7,0	758,51	0,987 2	7,3	953,52	0,989 4	7,6	989,38	0,989 4
3,005 0	6,0	758,72	0,987 5	6,3	953,73	0,989 6	6.5	989,60	0,989 6
3,056 0	3,0	758,95	0,987 8	3.1	953,97	0,989 9	3.2	989,85	0,989 9
3,132 0	5,0	759,25	0,988 2	5,2	954,29	0,990 2	5,4	990,18	0,990 2
3 156 0	18,0	759.53	0,988 6	18,7	954,58	0,990 5	19,4	990,48	0,990 5
3,204 0	1,2	759.99	0,989 2	1,3	955,06	0,991 0	1,3	990,98	0,991 0
3,245 0	3,0	760,08	0,989 3	3,1	955,15	0,991 1	3,2	991,07	0,991 1
3,317 0	12.0	760,92	0,990 0	12,6	955,71	0,991 7	13,1	991,66	0,991 7
3,344 0	3,0	760.82	0,990 2	3,1	955,92	0,991 9	3,2	991,88	0,991 9
3 450 0	12,2	761,62	0,991 3	12,8	956,77	0,992 8	13.3	992,75	0,992 8
3,573 0	11,0	763,05	0,993 2	11,5	958,26	0,994 3	11,9	994,30	0,994 3
3,765 0	9,0	764,97	0,995 7	9,4	960,27	0,996 4	9.8	996,38	0,996 4
4,045 0	6,9	767,20	0,998 6	7,2	962,59	0,998 8	7,5	998,79	0,998 9
> 4,045 0		768,31	1,000 0		963,75	1,000 0		1000,00	1,000 0

Table 2 — 100 selected ordinates for, at AM = 1,5, a) direct normal irradiance (field-of-view angle = 5,8°); b) hemispherical irradiance incident on a 37° tilted plane, equator-facing (ground albedo 0,2)

Wavelength fraction	a) Direct normal irradiance		b) Hemispherical irradiance	
F_{λ_k}	$E_{0 \to \lambda_k}$	λ_k	$E_{0 \to \lambda_k}$	λ_k
1	2	3	4	5
0,005	3,841 6	0,343 7	4,818 8	0,332 6
0,015	11,524 7	0,374 0	14,456 3	0,355 0
0,025	19,207 8	0,394 0	24,093 8	0,372 3
0,035	26,890 9	0,408 1	33,731 3	0,386 5
0,045	34 574 0	0,419 7	43,368 8	0,398 7
0,055	42,257 1	0,431 1	53,006 3	0,408 1
0,065	49,940 2	0,441 5	62,643 8	0,416 8
0,075	57 623 3	0,450 2	72 281 2	0,425 6
0,085	65 306 3	0,458 1	81,918 7	0,434 2
0,095	72,989 5	0,465 8	91,556 2	0,442 2
0,105	80 672 5	0,473 5	101,193 0	0,449 3
0,115	88,355 6	0,481 0	110,831 3	0,455 7
0,125	96 038 7	0,488 5	120,468 8	0,462 1
0,135	103,721 9	0,496 0	130,106 3	0,468 4
0,145	111,405 0	0,503 5	139,743 8	0,474 6
0,155	119,088 1	0,510 8	149,381 3	0,480 9
0,165	126,771 2	0,518 2	159,018 8	0,487 2
0,175	134,454 3	0,525 6	168,656 3	0,493 6
0,185	142,137 4	0,532 8	178,293 8	0,500 1
0,195	149,820 5	0,539 9	187,931 3	0,506 5
0,205	157,503 6	0,546 9	197,568 8	0,512 9
0,215	165,186 7	0,554 0	207,206 3	0,519 4
0,225	172,869 8	0,561 0	216,843 8	0,525 9
0,235	180,552 9	0,568 0	226,481 3	0,532 4
0,245	188,236 0	0,575 2	236,118 8	0,538 8
0,255	195,919 1	0,582 5	245,756 3	0,545 3
0,265	203,602 2	0,589 7	255,393 8	0,551 7
0,275	211,285 3	0,597 0	265,031 3	0,558 2
0,285	218,968 4	0,604 3	274,668 8	0,564 8
0,295	226,651 5	0,611 5	284,306 3	0,571 4
0,305	234,334 6	0,618 7	293,943 8	0,578 3
0,315	242,017 7	0,625 8	303 581 3	0,585 2
0,325	249,700 8	0,633 0	313,218 8	0,592 1
0,335	257,383 9	0,640 2	322,856 3	0,599 0
0,345	265,067 0	0,647 5	332,493 8	0,606 0
0,355	272,750 1	0,654 8	342,131 3	0,612 9
0,365	280,433 2	0,662 0	351,768 8	0,619 7
0,375	288,116 3	0,669 3	361,406 3	0,626 6
0,385	295,799 4	0,677 3	371,043 7	0,633 5
0,395	303,482 5	0,685 4	480,681 3	0,640 5
0,405	311,165 6	0,693 5	390,318 8	0,647 5
0,415	318,848 7	0,701 8	399,956 3	0,654 6
0,425	326,531 8	0,710 0	409,593 7	0,661 7
0,435	334,214 9	0,718 5	419,231 2	0,668 8
0,445	341,898 0	0,727 5	428,868 7	0,676 6

Wavelength fraction	a) Direct normal irradiance		b) Hemispherical irradiance	
F_{λ_k}	$E_{0 \to \lambda_k}$	λ_k	$E_{0 \to \lambda_k}$	λ_k
1	2	3	4	5
0,455	349,581 1	0,736 0	438,506 2	0,684 6
0,465	357,264 2	0,744 2	448,143 7	0,692 6
0,475	364,947 3	0,752 2	457,781 2	0,700 7
0,485	372,630 4	0,761 1	467,418 7	0,708 9
0,495	380,313 5	0,771 2	477,056 2	0,717 5
0,505	387,996 5	0,780 1	486,693 7	0,726 9
0,515	395,679 6	0,788 7	496,331 2	0,735 7
0,525	403,362 7	0,797 3	505,968 7	0,744 3
0,535	411,045 8	0,806 7	515,606 2	0,752 6
0,545	418,728 9	0,816 4	525,243 7	0,762 2
0,555	426,412 0	0,827 4	534,881 2	0,772 6
0,565	434,095 1	0,837 6	544,518 7	0,781 8
0,575	441,778 2	0,847 2	554,156 2	0,790 9
0,585	449,461 3	0,856 7	563,793 7	0,799 9
0,595	457,144 4	0,866 3	573,431 2	0,810 2
0,605	464,827 5	0,876 0	583,068 7	0,821 4
0,615	472,510 6	0,886 3	592,706 2	0,833 1
0,625	480,193 7	0,897 3	602,343 7	0,843 6
0,635	487,876 3	0,908 7	611,981 2	0,854 0
0,645	495,559 9	0,921 8	621,618 7	0,864 3
0,655	503,243 0	0,943 1	631,256 2	0,874 8
0,665	510,926 1	0,965 7	640,893 7	0,886 0
0,675	518,609 2	0,980 9	650,531 2	0,897 9
0,685	526,292 3	0,993 9	660,168 7	0,910 7
0,695	533,975 4	1,006 6	669,806 2	0,925 2
0,705	541,658 5	1,019 2	679,443 7	0,952 6
0,715	549,341 6	1,031 9	689,081 2	0,973 2
0,725	557,024 7	1,044 9	698,718 7	0,988 6
0,735	564,707 8	1,058 6	708,356 2	1,002 7
0,745	572,390 9	1,072 8	717,993 7	1,016 6
0,755	580,074 0	1,089 8	727,631 2	1,030 5
0,765	587,757 1	1,113 2	737,268 7	1,044 8
0,775	595,440 2	1,154 9	746,906 2	1,059 8
0,785	603,123 3	1,179 0	756,543 7	1,076 2
0,795	610,806 4	1,198 8	766,181 2	1,095 2
0,805	618,489 5	1,218,0	775,818 7	1,135 0
0,815	626,172 6	1,237 3	785,456 2	1,171 1
0,825	633,855 7	1,256 8	795,093 7	1,194 6
0,835	641,538 8	1,276 3	804,731 2	1,216 8
0,845	649,221 9	1,297 7	814,368 7	1,239 0
0,855	659,905 0	1,328 7	824,006 2	1,261 4
0,865	664,588 1	1,478 0	833,643 7	1,283 7
0,875	672,271 2	1,522 0	843,281 2	1,311 7
0,885	679,954 3	1,553 2	852,918 7	1,453 5
0,895	687,637 4	1,585 9	862,556 2	1,518 9
0,905	695,320 5	1,620 9	872,193 7	1,556 0
0,915	703,003 6	1,656 4	881,831 2	1,595 4
0,925	710,686 7	1,695 5	891,468 7	1,637 5
0,935	718,369 8	1,738 1	901,106 2	1,681 4
0,945	726,052 9	1,966 0	910,743 7	1,732 4
0,955	733,736 0	2,088 0	920,381 2	1,976 4
0,965	741,419 1	2,190 5	930,018 7	2,116 7
0,975	749,102 2	2,309 5	939,656 2	2,247 1
0,985	756,785 3	2,523 5	949,293 7	2,418 2
0,995	764,468 4	3,714 8	958,931 2	3,637 1

Table 3 — 50 selected ordinates for, at AM = 1,5 a) direct normal irradiance (field-of-view angle = 5,8°); b) hemispherical irradiance incident on a 37° tilted plane, equator-facing (ground albedo 0,2)

Wave-length fraction	a) Direct normal irradiance		b) Hemispherical irradiance	
F_{λ_k}	$F_{0-\lambda_k}$	λ_k	$F_{0-\lambda_k}$	λ_k
1	2	3	4	5
0,010	7,683 1	0,361 2	9,637 5	0,344 6
0,030	23,049 3	0,401 7	28,912 5	0,379 5
0,050	38,415 5	0,425 4	48,187 5	0,403 5
0,070	53,781 7	0,445 8	67,462 5	0,421 1
0,090	69,147 9	0,462 0	86,737 5	0,438 4
0,110	84,514 1	0,477 2	106,012 5	0,452 5
0,130	99,880 3	0,492 3	125,287 5	0,465 2
0,150	115,246 5	0,507 2	144,562 5	0,477 8
0,170	130,612 7	0,521 9	163,832 5	0,490 4
0,190	145,978 9	0,536 4	183,112 5	0,503 3
0,210	161,345 1	0,550 5	202,387 5	0,516 1
0,230	176,711 3	0,564 5	221,662 5	0,529 2
0,250	192,077 5	0,578 8	240,937 5	0,542 0
0,270	207,443 7	0,593 4	260,212 5	0,555 0
0,290	222,809 9	0,607 9	279,487 5	0,568 0
0,310	238,176 1	0,622 3	298,762 5	0,581 7
0,330	253,542 3	0,636 6	318,037 5	0,595 6
0,350	268,908 5	0,651 1	337,312 5	0,609 5
0,370	284,274 7	0,665 7	356,587 5	0,623 2
0,390	299,640 9	0,681 4	375,862 5	0,637 0
0,410	315,007 1	0,697 7	395,137 5	0,651 1
0,430	330,373 3	0,714 3	414,412 5	0,665 3
0,450	345,739 5	0,731 7	433,687 5	0,680 6
0,470	361,105 7	0,748 2	452,962 5	0,696 7
0,490	376,471 9	0,766 6	472,237 5	0,713 2
0,510	391,838 1	0,784 4	491,512 5	0,731 3
0,530	407,204 3	0,801 8	510,787 5	0,748 5
0,550	422,570 5	0,822 0	530,062 5	0,768 0
0,570	437,936 7	0,842 5	549,337 5	0,786 3
0,590	453,302 9	0,861 5	568,612 5	0,805 1
0,610	468,669 1	0,880 9	587,887 5	0,827 4
0,630	484,035 3	0,902 7	607,162 5	0,848 8
0,650	499,401 5	0,929 3	626,437 5	0,869 6
0,670	514,767 7	0,973 3	645,712 5	0,891 9
0,690	530,133 9	1,000 2	664,987 5	0,917 8
0,710	545,500 1	1,025 6	684,262 5	0,964 5
0,730	560,866 3	1,051 8	703,537 5	0,995 7
0,750	576,232 5	1,081 3	722,812 5	1,023 5
0,770	591,598 7	1,136 4	742,087 5	1,052 3
0,790	606,964 9	1,189 0	761,362 5	1,085 7
0,810	622,331 1	1,227 7	780,637 5	1,156 8
0,830	637,697 3	1,268 5	799,912 5	1,205 7
0,850	653,063 5	1,310 7	819 187 5	1,250 2
0,870	668,429 7	1,503 5	838,462 5	1,296 6
0,890	683,795 9	1,569 2	857,737 5	1,496 1
0,910	699,162 1	1,638 4	877,012 5	1,575 1
0,930	714,528 3	1,716 8	896,287 5	1,659 0
0,950	729,894 5	2,034 2	915,562 5	1,774 8
0,970	745,260 7	2,248 4	934,837 5	2,178 2
0,990	760,626 9	3,317 9	954,112 5	3,089 8

Annex A
(informative)

Atmospheric parameters of the model atmosphere

The 1962 US Standard Atmosphere Model[5] with a rural aerosol was used to produce the data for this part of ISO 9845. This atmospheric model exhibits the following parameters for a vertical path from sea level to the top of the atmosphere:

— precipitable water vapour = 14,2 mm

— total ozone = 3,4 mm

— turbidity (optical depth of aerosol at 0,5 μm) = 0,27

Atmospheric parameters, such as temperature, pressure, aerosol density, air density, and the density of nine molecular species, are defined at 33 levels within the atmosphere. Atmospheric parameters vary exponentially between the 33 levels. The precipitable water vapour and total ozone are derived by integrating water vapour and ozone concentrations throughout the exponentially varying 33 levels. The absorption and scattering properties of the aerosol are calculated with Mie theory. A bimodal, log-normal aerosol size distribution with a complex index of refraction that varies with wavelength is used to define the aerosol. The turbidity used corresponds to a sea-level meteorological optical range of 23 km.

NOTE 6 The standard data presented here were calculated for the sun at a solar zenith angle of 48,19° and an air mass of 1,5. For example, approximately 50 % of the annual energy output at selected US locations is at air mass values greater than AM 1,5 for collector surfaces facing south and tilted at the latitude angle[12].

Annex B
(informative)

Computational technique for tabulated values derived from the spectral irradiance

B.1 Integrated irradiance

The integrated irradiance values $E_{0\to\lambda_i}$ presented in columns 3, 6 and 9 and used in columns 4, 7 and 10 of table 1 were computed using a modified trapezoidal integration technique. More specifically,

$$E_{0\to\lambda_i} = E_{0\to\lambda_1} + \sum_{j=1}^{i-1} \frac{E_{\lambda_{j+1}} + E_{\lambda_j}}{2} \Delta\lambda_j$$

where

$$\Delta\lambda_j = \lambda_{j+1} - \lambda_j$$

and $E_{0\to\lambda_1}$ is the contribution prior to the first tabulated wavelength. This is estimated as half of the first trapezoidal area interval by:

$$E_{0\to\lambda_1} = \frac{1}{2}\,\frac{E_{\lambda_1} + E_{\lambda_2}}{2}(\lambda_1 - \lambda_2)$$

Similarly, $E_{\lambda_{N\to\infty}}$, the total irradiance beyond the last tabulated wavelength λ_N, is estimated as:

$$E_{\lambda_{N\to\infty}} = \frac{1}{2}\,\frac{E_{\lambda_N} + E_{\lambda_{N-1}}}{2}(\lambda_N - \lambda_{N-1})$$

leading to an expression for the solar irradiance:

$$E_{0\to\infty} = E_{0\to\lambda_N} + E_{\lambda_{N\to\infty}}$$

B.2 Selected ordinates

Wavelength values were derived from the selected ordinates by an area interpolation procedure. The kth selected ordinate wavelength was derived from:

$$F_k = F_{i+1} - \frac{\Delta F_i}{\Delta\lambda_i}\Delta\lambda_k$$

where

$$F_i = E_{0\to\lambda_i}/E_{0\to\infty}$$

$$\Delta\lambda_k = \lambda_{i+1} - \lambda_k$$

and

$$F_i < F_k < F_{i+1}$$

To compute λ_k (the wavelength at midpoint of the equal energy interval):

$$\lambda_k = \lambda_i + \left(\frac{E_{0\to\lambda_k} - E_{0\to\lambda_i}}{E_{0\to\lambda_{i+1}} - E_{0\to\lambda_i}}\right)(\lambda_{i+1} - \lambda_i)$$

where

$$\lambda_i < \lambda_k < \lambda_{i+1}$$

and

$$E_{0\to\lambda_k} = F_{\lambda_k}E_{0\to\infty}$$

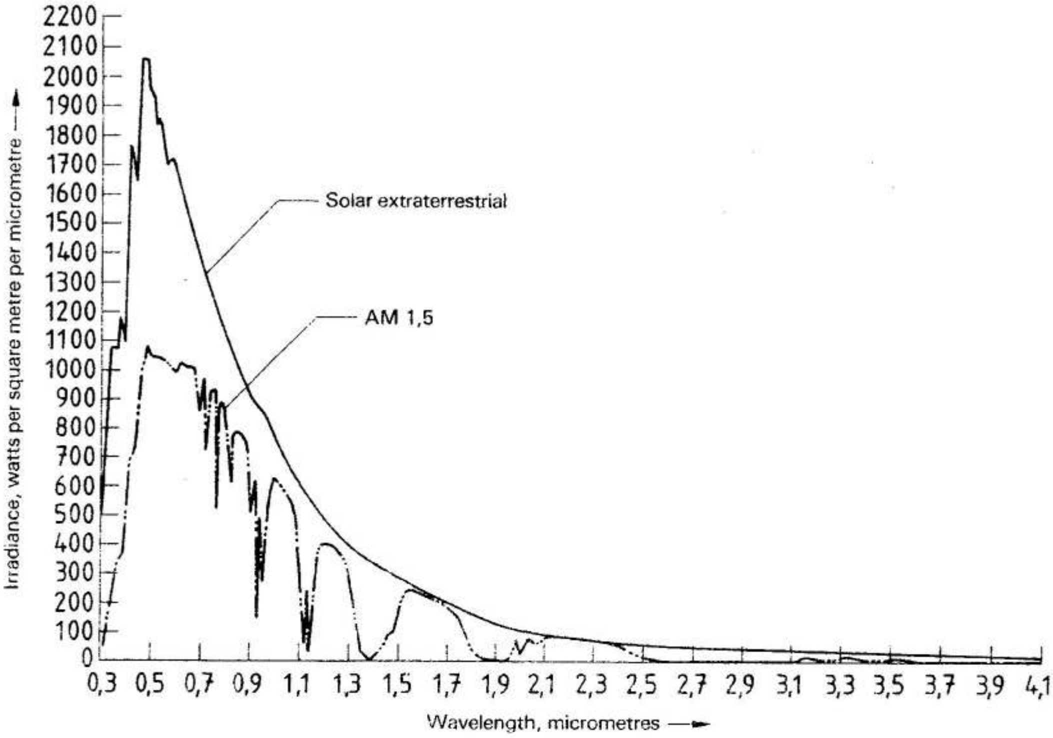
The value of F_k appropriate for the kth selected ordinate is given by:

$$F_k = \frac{2k-1}{2m}$$

where m is the number of selected ordinate points desired (50 or 100).

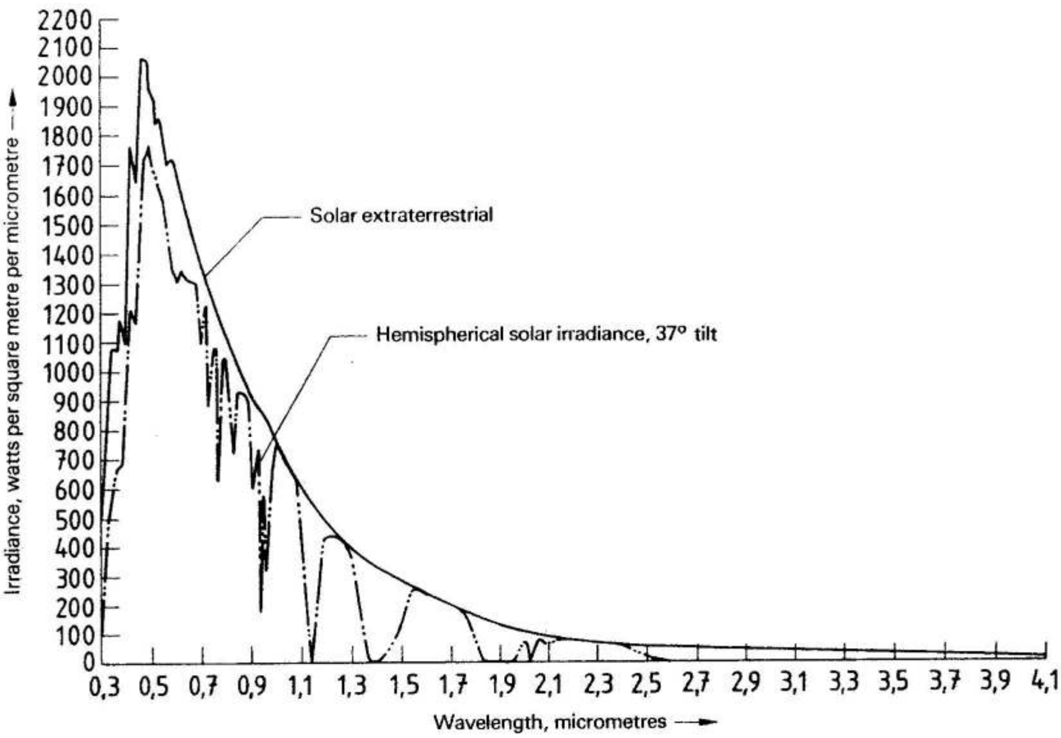
Annex C
(informative)

Plots of solar irradiance



NOTE — US Standard Atmosphere 23 km visible rural aerosol (albedo = 0.2; AM = 1,5).

Figure C.1 — Plot of direct normal irradiance



NOTE — US Standard Atmosphere 23 km visible rural aerosol (albedo = 0,2; AM = 1,5).

Figure C.2 — Plot of hemispherical solar irradiance